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LABORATORY



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REPORT NO. 710/78

PHOTOGRAPHIC STUDY OF IMPACT  
OF BALL AND ARMOR PIERCING AMMUNITION  
ON ARMOR PLATE

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WATERTOWN ARSENAL, WATERTOWN, MASS.

By

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December 21, 1936  
WATERTOWN ARSENAL  
WATERTOWN, MASS.

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Report No. 710/78  
Watertown Arsenal

December 21, 1936

Photographic Study of Impact  
of Ball and Armor Piercing Ammunition  
on Armor Plate

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Purpose

The object of this investigation was:

1. To make a photographic study of the impact of ball and armor piercing bullets in homogeneous armor plate.
2. To study the nature of deformation at areas of bullet impact.

Conclusions

1. Silhouette photographs of impact of Cal. .28 and .30 ball ammunition on plate reveal sound waves as they are reflected from the back side of the plate and the start of new waves as the bullet pierces the plate.
2. Photographic studies taken by reflected light of different stages of impact of Cal. .30 armor piercing bullets with striking velocity varying from 2100 foot seconds to service velocity at a distance of 100 yards indicate that:-
  - (a) Incandescent particles of lead are evident at moment of impact.
  - (b) The jacket metal peels off the core and is flattened out on the plate at early stages of impact.
  - (c) Lead splash and particles of jacket metal are blown off at the area of impact.

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3. Spectrographic analysis of metallic particles and gray deposit collected on wooden members of the armor plate support is as follows:

- a. Metallic Particles - Cu, Pb, Zn
- b. Gray deposit - Cu, Pb, Fe, Al, Zn, Mn, Cr.

4. Distortion on the rear face of armor plate sometimes occurs .5" from actual point of penetration.

5. Distortion of the outer surface layers of plate near the area of impact as revealed by macroscopic examination is typical of that produced by torsion.

6. Evidence of torsional impact produced by bullet impact on plate is revealed in the following cases:

- (a) The study of microscopic examination of the metal at areas of impact.

- (b) Spalls which have been blown off the back of the plate,

- (c) A study of spiral fractures on the rear face of penetrated plate.

### Introduction

In connection with the present study of the mechanism of penetration of armor plate, Professor H. E. Edgerton of the Massachusetts Institute of Technology has made a very interesting and instructive series of photographs of impacts of armor piercing bullets on homogeneous armor plate, one-half inch in thickness.

Professor Edgerton has recently perfected the technique of taking accurately timed photographs of bullets in flight, and at various stages of impact on plate, the details of which are given below.

#### EXPERIMENTAL PROCEDURE

##### 1. Method of Taking Accurately Timed Photographs

Preliminary experiments were conducted at the Massachusetts Institute of Technology on the photographic study of impact of caliber .22 and .30 ball ammunition on thin sheet rubber, 18 gauge aluminum and 18 gauge galvanized iron sheet. Both silhouette and reflected light photographs were taken.

An extensive photographic study was made at Watertown Arsenal during September and October 1936 under the direction of Professor Edgerton in regard to the impact of caliber .30 armor piercing bullets on standard chromium-molybdenum-vanadium homogeneous armor plate heat treated to a Brinell hardness of 418. The striking velocities of the bullets used varied from 2100 foot-seconds to service velocity at a distance of 100 yards. The size of this plate was 12 x 12 x 1/2". All scale on the plate was removed by means of sand blasting before the test.

Photographic studies were also made on the rear face of a sand blasted plate, before, during and after bullet impact in order to determine the nature of the mechanism of penetration on this particular face.

Furthermore an attempt was made to study the extent of deformation at the area of penetration on the rear face of the plate. To accomplish this, the rear face of the plate was ground, polished and parallel lines one-half inch apart were engraved horizontally and vertically on this face. A photographic study was made before, during and after impact, in order to determine the amount of distortion of the lines.

All plates were securely clamped to a wooden framework, the rear face of the plate being unprotected.

The apparatus used for taking the photographs shown in Figure 1 consisted of the following units:

(a) A Rochelle-salt piezo-electric crystal and amplifier actuated the flash of light at the correct instant. The amplifier consisted of four stages of vacuum tubes plus a Thyatron spark producing circuit. This high voltage spark (about 50,000 volts) was used to trip the argon lamp described below:

(b) A specially constructed argon filled lamp was used for producing the very short flash of light and was excited by a condenser charge. The leads

for this tube were designed to minimize the inductance in the condenser discharge circuit. A sketch of the general arrangement is shown in Figure 1, which shows the connections and the position of the camera and the lamp. Argon gas at a pressure of forty centimeters (of mercury) was put into the tube.

The seals were 40 mil tungsten and the ends of the seals were used as electrodes. A condenser of 0.5 microfarad capacity, charged to about 6000 volts was connected directly across the special argon tube.

(c) The camera used for taking the preliminary impact studies was 9 x 12 cm Zeiss Ikon with an f4.5 lens of 150 mm focal length. The lens was set in this case at f11.

In the photographic study of armor piercing impact a f 7.7 lens wide open with 173 mm focal length was used. All photographs were taken upon Eastman "Verichrome" film.

## 2. Macro and Microscopic Examination

Macro and microscopic examination was made on plates tested at Aberdeen Proving Ground in order to study the flow of metal at areas of bullet impact.

## 3. Spectrographic Analysis of Deposit from Bullet Impact

Spectrographic analysis was made on some of the deposit taken from bullet impact on plate. This deposit was removed from wooden supports of the

framework supporting the armor plate.

## Discussion

### 1. Photographic Study

The piezo-electric-crystal method of timing the flash works very consistently and quickly. For example; the variation of the position of the bullet from the mean value in twelve (12) pictures was less than  $1/2"$ . Most of this variation can be accounted for by dispersion of the ammunition.

The light flashes early if the full sensitivity of the amplifier is used. This is apparently due to the sound wave that is transmitted through the gun support and the cement floor to the crystal stand. Adjustment of the crystal position was first approximately determined by calculation from the expected velocity of the bullet. Final adjustment was made visually since the bullet can be seen with the flash of light from the argon tube.

The photographically-effective duration of light from the argon tube is about two micro seconds. Assuming a bullet velocity of 2700 feet per second the bullet will move 0.06 of an inch, while the exposure is being made. The slightly blurred edges of the bullets in the photographs is caused by this effect though some of the blurring

may be caused by lack of accurate focus. The exposure time is limited principally by inductance in the condenser and in the leads. However, the lamp may greatly extend the exposure time if it allows oscillations in the condenser or if the gas in the tube continues to glow after the current has stopped. The tube whose specifications are given on the schematic layout of the arrangement has sufficient resistance to damp out the oscillations and has a very faint after glow that is not effective from a photographic standpoint. Reduction of exposure time should be possible with a condenser of lower inductance. The inductance of the 0.5 microfarad condenser used in these experiments together with the inductance of the leads, gave the circuit a natural frequency of about 275 kilocycles.

A description of the photographs attached is given below:

Fig. 2, 3, and 4 illustrate silhouette photographs of Caliber .30 ball ammunition service velocity in flight, during penetration and after penetrating an eighteen gauge aluminum sheet. These photographs illustrate sound waves propagated from the bullet in flight and as they are reflected from the back side of the plate and the start of the new wave as the bullet pierces the plate. These photographs



were taken about 10 feet in front of the muzzle of the rifle and the crystal was placed about two or three feet beyond the point at which the bullet was photographed.

Figures 5, 6, 7, 8, 9, 10, 11 and 12, show an interesting series of photographs of Cal. .30 Armor Piercing service velocity bullet in various stages of impact on heat treated homogeneous one half inch Armor plate at a distance of one-hundred yards. The approach of the bullet to plate is shown in Figures 5 and 6. At the immediate moment of contact of bullet on plate, flares probably of incandescent lead particles are evident, see Figure 7. On further penetration of plate the jacket metal apparently peels off and is thrust forward on plate, see Figures 8 and 9. Later stages of impact of the bullet are illustrated in Figures 10, 11 and 12 in which particles of jacket metal and lead splash are blown from the area of impact. Unfortunately the actual penetration of the plate is masked by flying particles during the impact.

Photographs taken on the back side of the plate before, during, and after impact are shown in Figures 13, 14, 15, 16, 17 and 18. Spalls and incandescent particles are shown flying off the

plate in Figure 14. Progress of bullet penetration of the rear face of the plate are illustrated in Figures 17 and 18.

A study of Figure 20 shows slight bulging of metal (within area marked) during early stages of impact. After penetration however, the actual impact, Figure 21, actually occurred 0.5 inches from this bulge. This observation is important in the study of occurrence of elastic deformation during the early stages of bullet impact.

An attempt was made to study the flow of metal after bullet impact on previously polished and ruled back face of a plate. The distortion of the lines near the impact is not pronounced as shown in Figures 22, 23, and 24.

## 2. Macro and Microscopic Examination

A short discussion of a macro and microscopic study of the mechanism of penetration of armor plate tested at Aberdeen Proving Ground is included in this report as follows:

It has been observed recently that in plates of the standard chromium-molybdenum vanadium composition and in other compositions that flow and faulting of the metal occurs in the vicinity of bullet impact, Figures 25 and 26. There evidently has been sufficient

heat generated by the impact of the bullet to cause the metal near the impact to fault or slip along paths of slip of no particular orientation. These slip lines or white layers as they appear in the photographs are harder than the surrounding metal and are believed to be martensitic due to the fact that these paths of slip were heated above the critical point of the metal and quickly cooled by conduction of heat by the surrounding metal.

Figure 27 illustrates the flow of metal near the surface of armor plate at area of impact. This structure was revealed about .1 inch below the actual surface of the plate. Evidently the bullet in the early stages of impact may be compared to a high speed boring machine, the heat at time of impact being sufficient to cause torsional flow of metal. In many cases spalls which are blown off the rear face of armor plate show evidence characteristic of torsional flow.

One of these spalls was examined under the microscope and it was found that typical torsional deformation was present.

A rear face of a penetrated armor plate, shown in Figure 29 is an example of spalls blown off in a spiral formation, this illustration being suggestive of torsional impact.

Another case of rupture caused by bullet impact and possibly by torsional flow of metal is shown in Figure 28. This rupture shows actual voids, (black) in the form of well defined twists.

3. Spectrographic Analysis of Deposit from Bullet Impact.

1. Analysis of metallic particles removed from deposit, - Cu, Pb, Zn

2. Analysis of gray powder - Cu, Pb, Fe, Al, Zn, Mn, Cr.

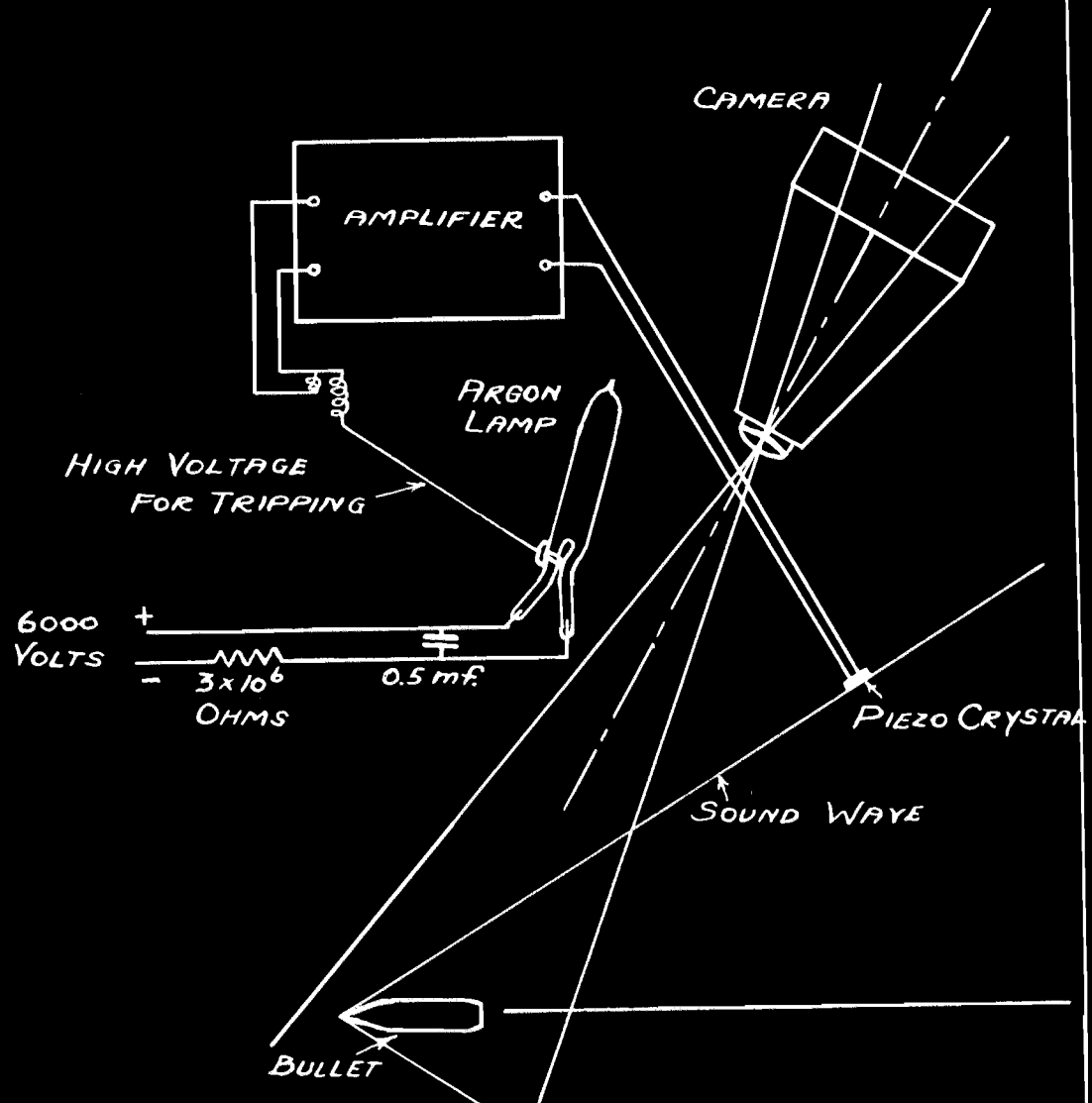
The analysis indicated that lead was the metal in excess in the deposit.

Respectfully submitted,

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# ARRANGEMENT FOR PHOTOGRAPHING BULLETS WITH REFLECTED LIGHT



## LAMP DATA

GAS - ARGON  
PRES. - 40 CM.-HG.  
GAP -  $2\frac{1}{2}$  IN.  
TUBE - 10 MM. I.D. PYREX  
ELECTRODES - TUNGSTEN

FIG. 1.

AUGUST 1 1936

H.E. EDGERTON

S.K. # 710/103  
Rpt. - 710/71

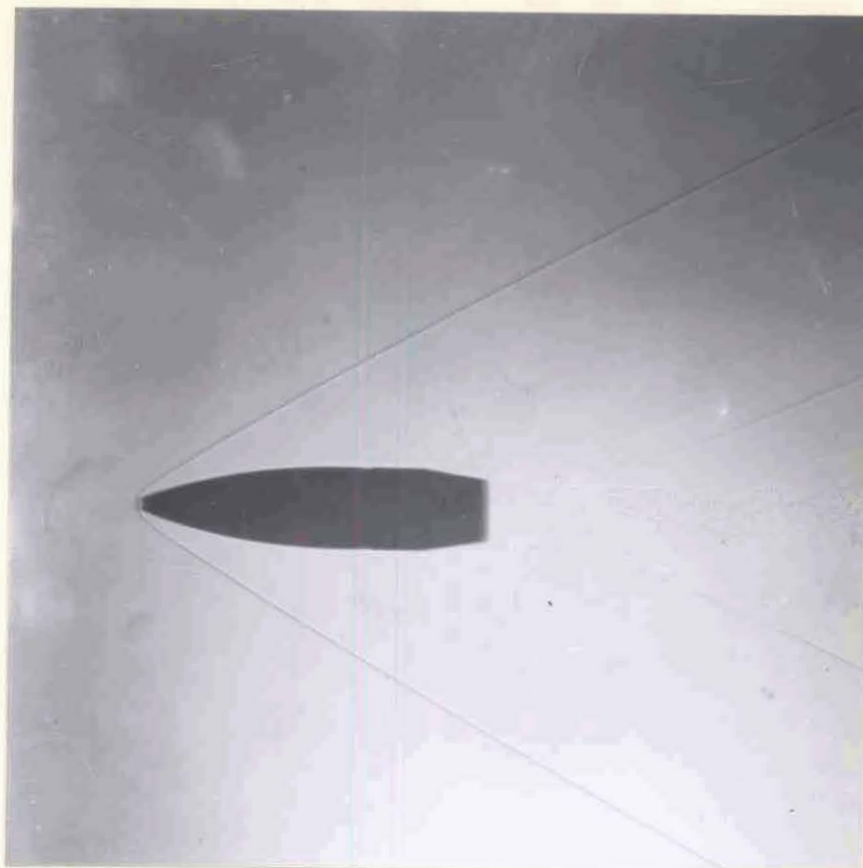


Figure 2

Silhouette photograph of Cal. .30  
ball service velocity ammunition in flight.

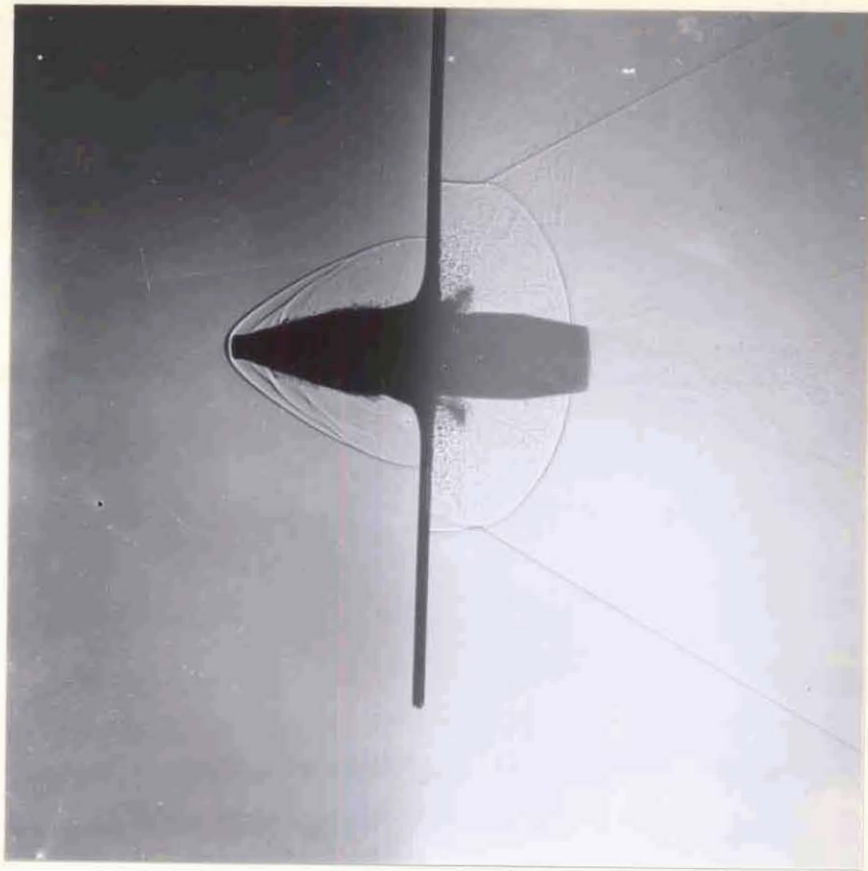


Figure 3

Silhouette photograph of Cal. .30 ball  
service velocity ammunition penetrating an 18 gauge  
aluminum sheet

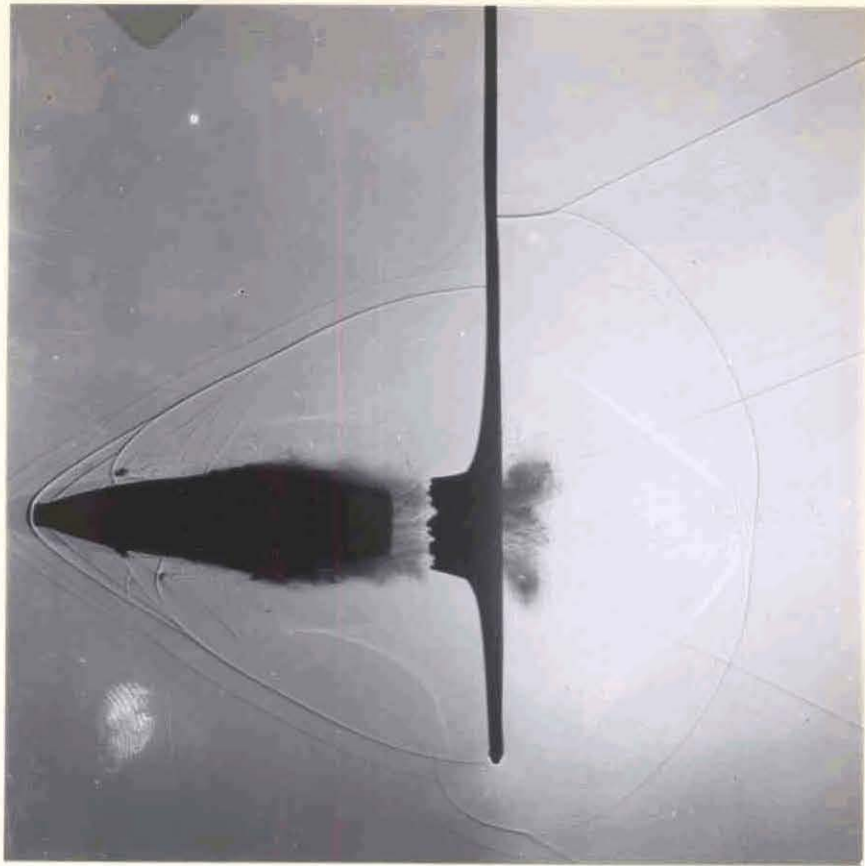


Figure 4

Silhouette photograph of Cal. .30  
service velocity ammunition after penetrating.



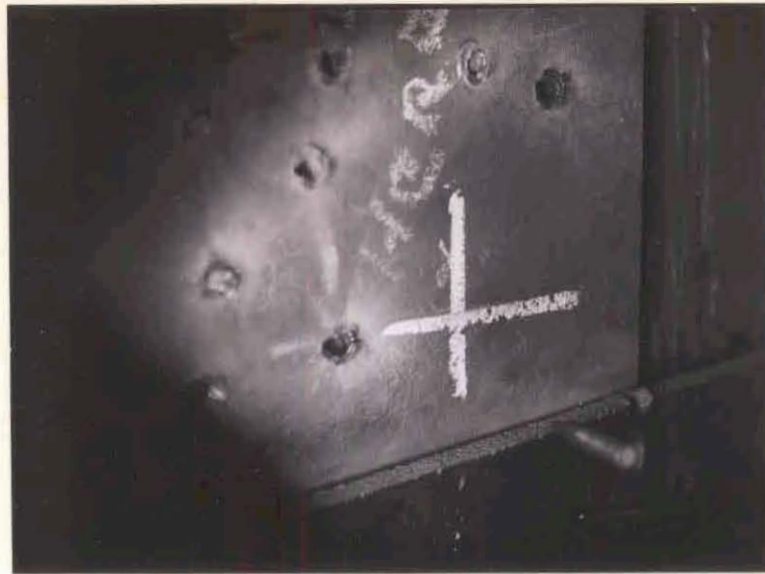


Figure 5 - Photograph by reflected light of  
Cal. .30 Armor Piercing Service Velocity  
bullet in flight (striking distance  
100 yards)



Figure 6 - Photograph by reflected light of  
Cal. .30 Armor Piercing Service  
Velocity bullet in flight just about to  
strike Armor Plate. Striking distance  
100 yards.



Figure 7 - Photograph by reflected light of Caliber .30 Armor Piercing Service Velocity bullet at the instant of striking Armor Plate. Note flares - probably burning lead. Striking distance 100 yards.

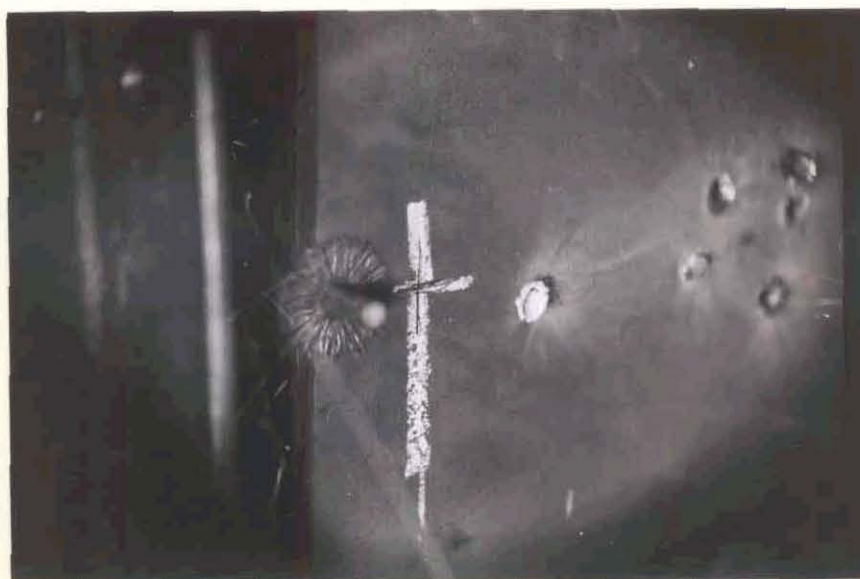


Figure 8 - Photograph by reflected light of Caliber .30 Armor Piercing Service Velocity bullet just striking Armor Plate. Note peeling off jacket metal from bullet core. (striking distance 100 yards).

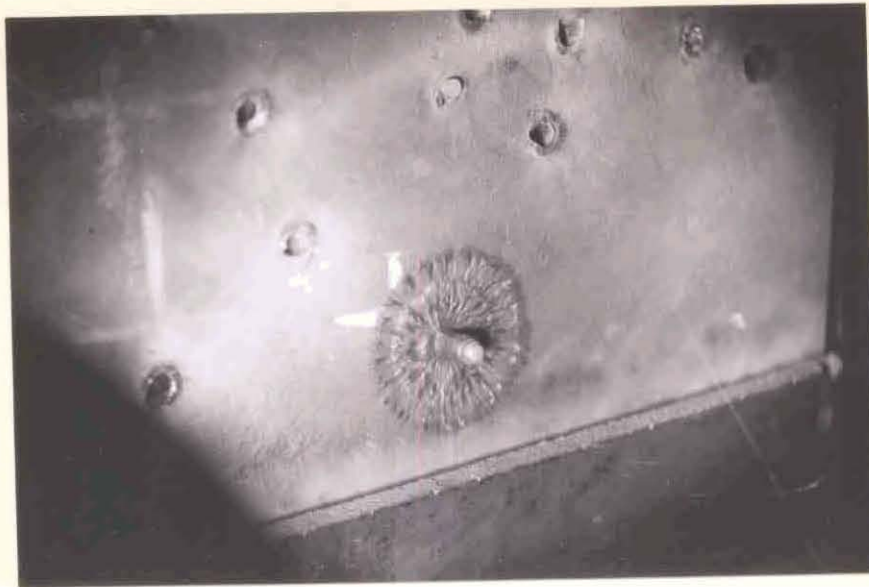


Figure 9 - Photograph by reflected light of Caliber .30 Armor Piercing serviced velocity bullet in progress of penetration of Armor Plate. (striking distance - 100 yards.)

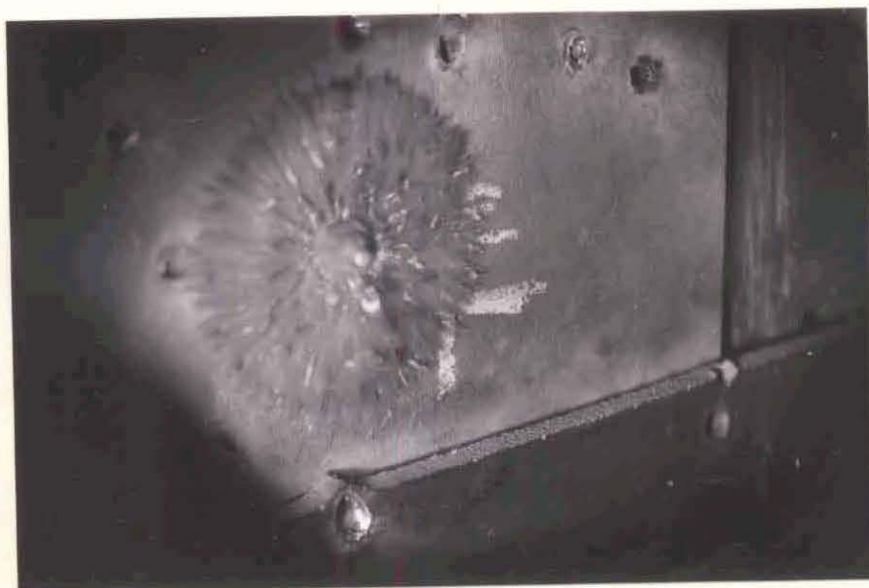


Figure 10 - Photograph by reflected light of Cal..30 Armor Piercing service velocity bullet in progress of penetrating Armor Plate. Note lead splash and particles of jacket metal being blown from impact. (striking distance 100 yards).





Figure 11 - Photograph by reflected light of Caliber .30 Armor Piercing service velocity bullet in progress of penetrating Armor Plate. (Striking distance - 100 yards.)

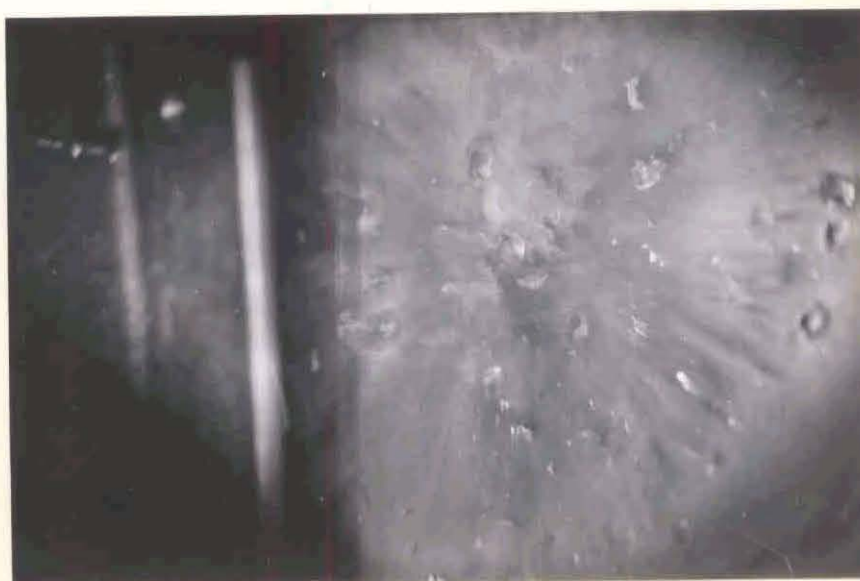


Figure 12 - Photograph by reflected light of Caliber .30 Armor Piercing service velocity bullet in progress of penetrating Armor Plate. (striking distance - 100 yards).



Figure 13 - Back face before impact

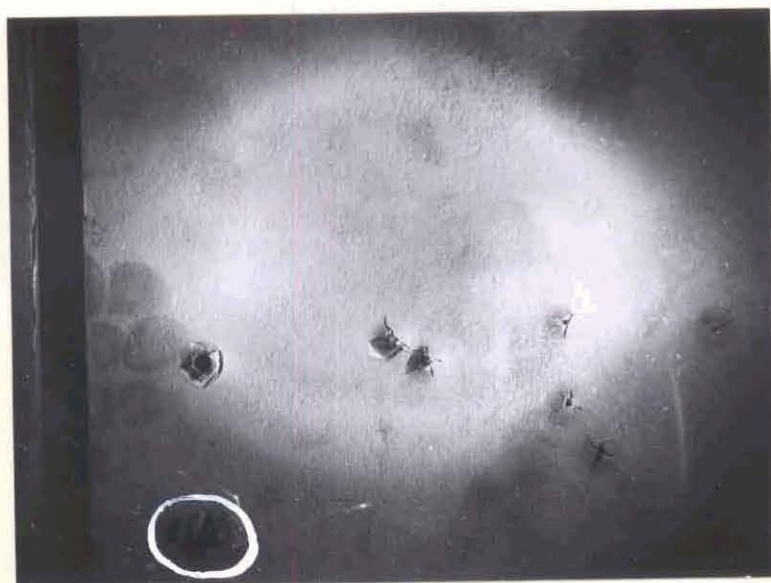


Figure 14 - Back face during late stage of impact. Spalls flying off and incandescent particles.

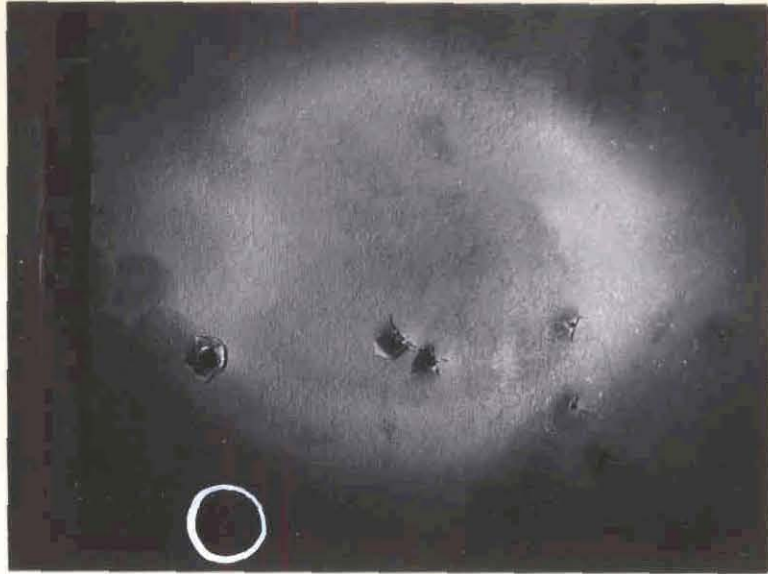


Fig. 15 - Back face after impact. Photographs taken by reflected light. Ammunition - Caliber .30 Armor Piercing service velocity at a distance of 100 yards.



Figure 16 - Back face before impact.



Figure 17 - Back face during impact.  
Nose of bullet core appearing through  
back of plate.



Figure 18 - Back face of plate. Fragments  
blown off. Photographs taken by reflected light.  
Ammunition Caliber .30 Armor Piercing service  
velocity at a distance of 100 yards.





Figure 19 - Back face before impact.



Back face.  
Figure 20 - During early stages of impact.  
Note crack appearing.



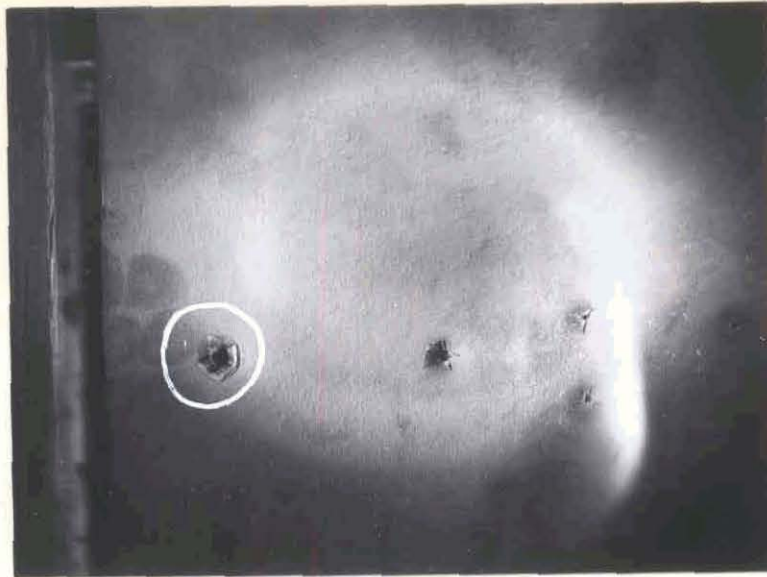


Figure 21 - Back face after impact.  
Photograph taken by reflected light.  
Ammunition - Caliber .30 Armor Piercing service  
velocity at a distance of 100 yards.

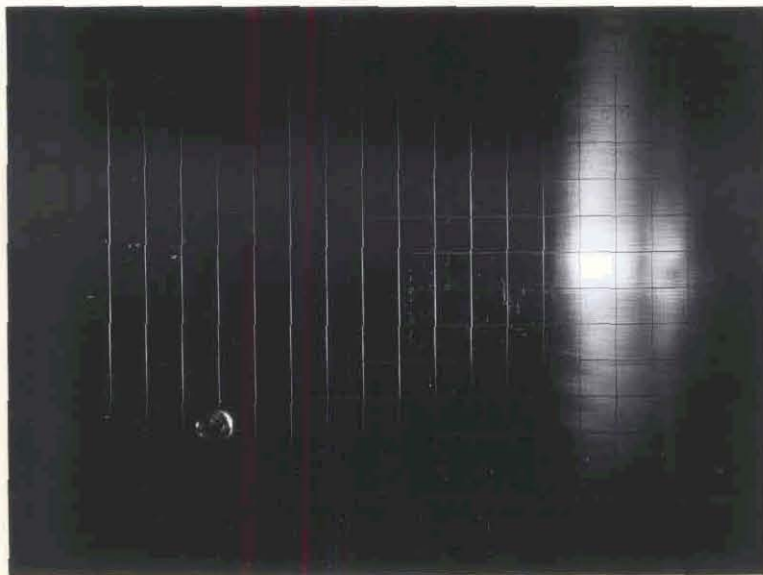


Figure 22 - Polished ruled rear face before  
impact.

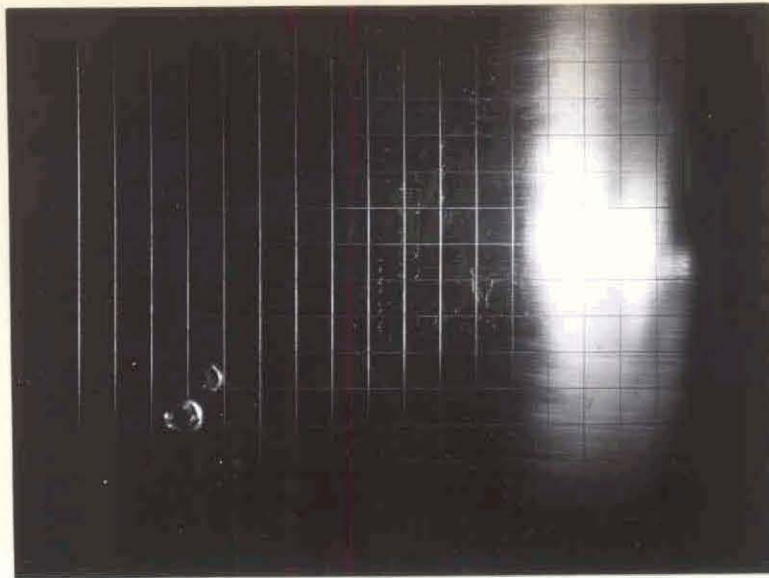


Figure 23 - Polished ruled rear face  
during late stage of impact.

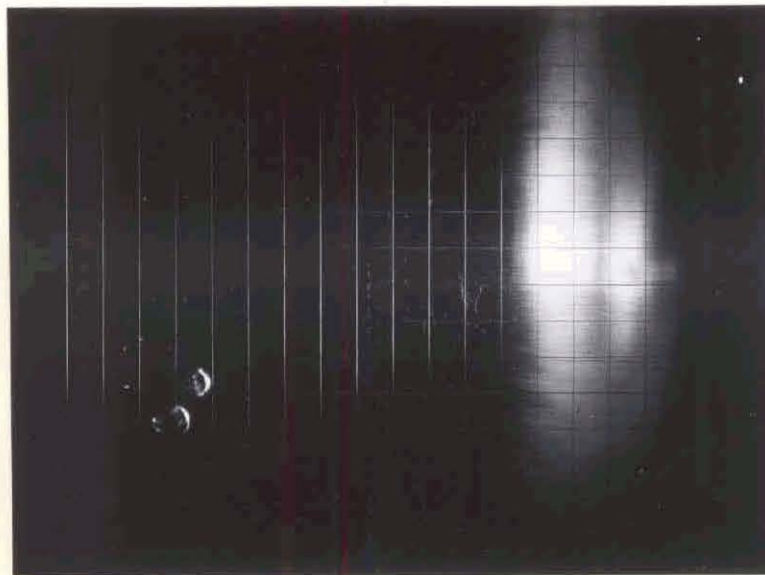


Figure 24 - Polished ruled rear face  
after impact.

Photographs taken by reflected light.  
Ammunition - Cal. .30 Armor Piercing  
2100 foot seconds velocity at a distance of 100 yds.

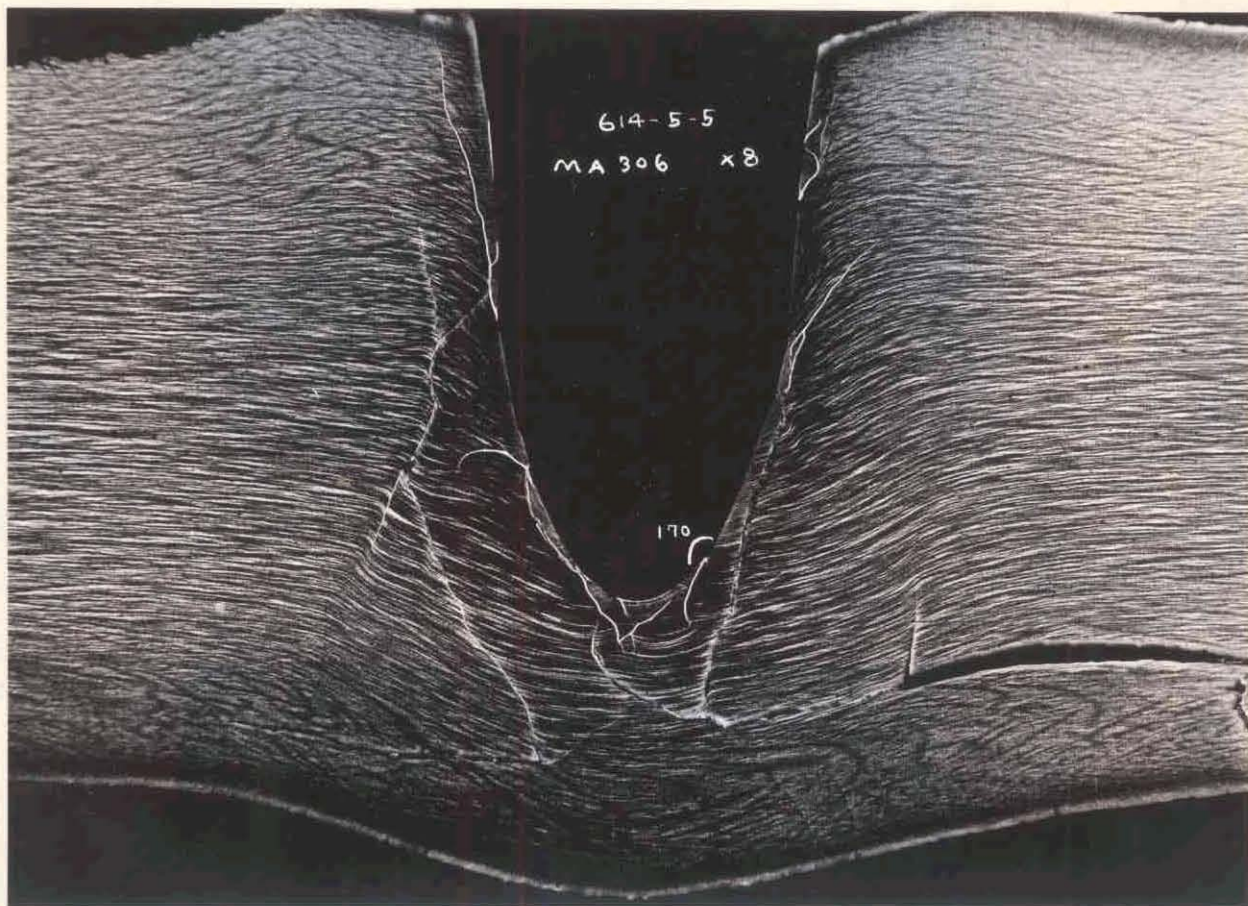


Figure 25

Macrostructure of cross section of bullet  
hole. C .51%, Cr 1.21%, Mo .56%, Va .29%.  
Etched in Rosenhain-Houghton's Reagent 5X.





Figure 26

Same as above at bottom of bullet hole.  
Etched in 1% Nital - 100X

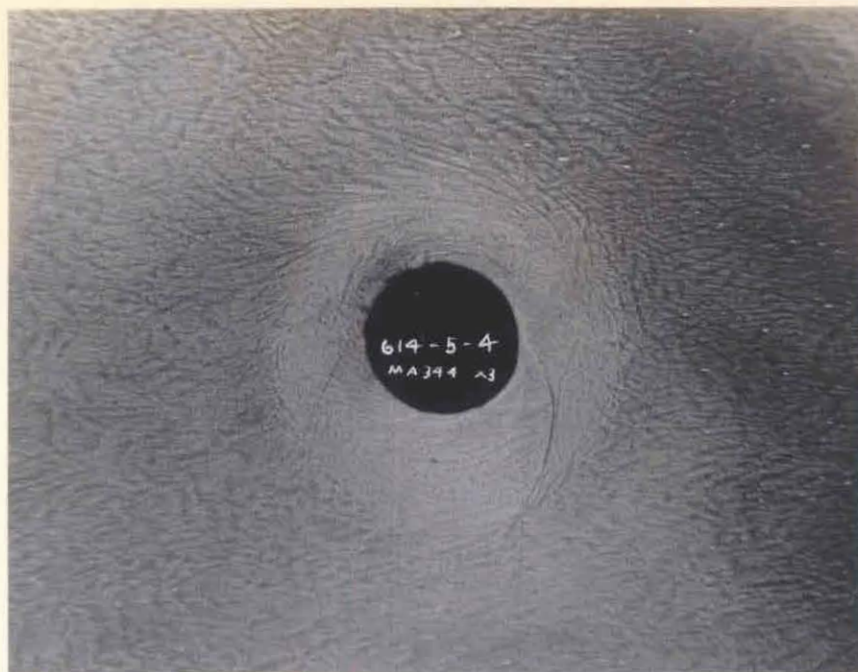


Figure 27 - Macro structure at bullet hole;  
plane parallel to surface. Complete penetration.  
C .51%; Cr 1.21%; Mo .56%; V .29%;  
Etched in Rosenhain-Houghton's reagent - X3



Figure 28 - Micro structure near bottom of  
bullet hole. Arrow indicates bullet penetration.  
C .425; Ni 3.58; Si 2.01. Partial penetration.  
Etched in Sodium Picrate - X1000



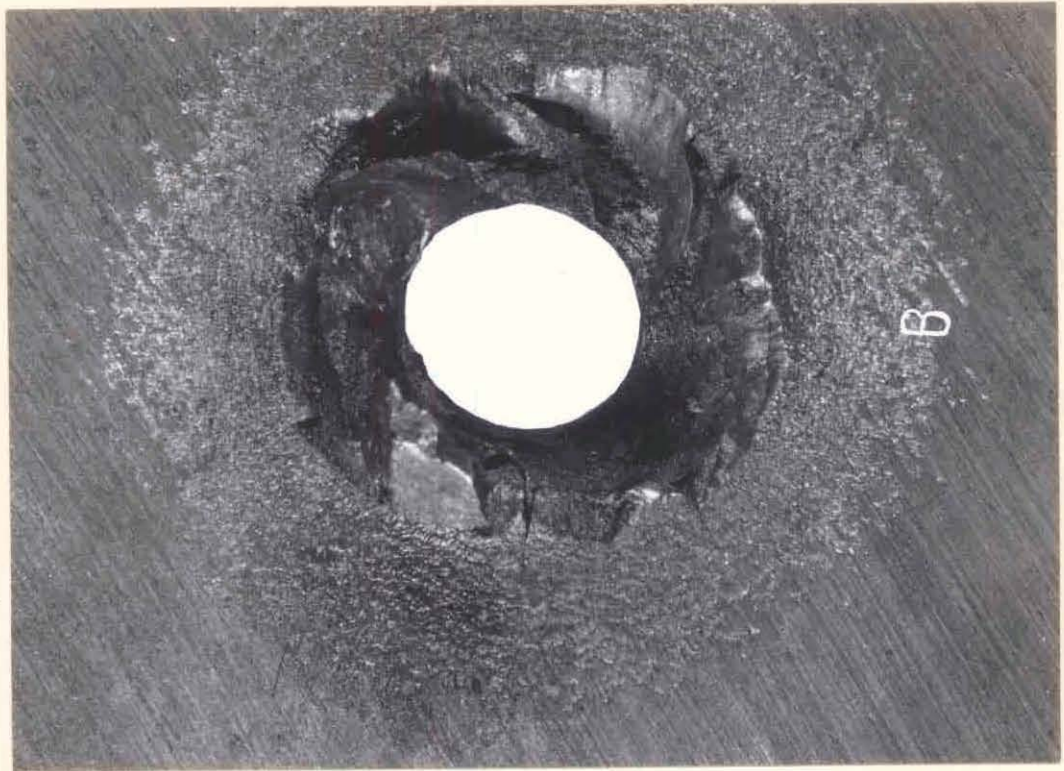


Figure 29 - Photograph of rear face of standard chromium-molybdenum-vanadium plate showing evidence of torsional impact; that is, spalls and fragments were blown off in spiral formation X 5.